Progress Report

Grant #731009

Ultra-Efficient Generators & Diesel Electric Propulsion

Genesis Machining & Fabrication

Reporting Dates: 1/2013-3/2013

Deliverables Submitted:

No deliverables due at this time.

Budget:

See attached files for receipt copies and receipt spreadsheet.

We are invoicing for $3,146.60 in materials and supplies and $3,950.00 in salary. We are requesting $3000.00 of the $3146.60 in materials from the funds for the task 2 period: Performance testing of EV and PDM as these expenses are connected to implementing the data-acquisition system, and other systems required for performance testing.

Schedule Status:

We are on schedule to complete the next milestone by the end of March 2013: Completing the TRL-6 UMIC and EV testbed.

Percent Complete:

We are about 95% complete with the first milestone listed in the grant schedule. We have completed and tested our TRL-6 UMIC for basic functionality in our EV testbed vehicle. This means that the controller spins the drive-train from battery power when the throttle pedal is pressed. Additionally, we have all basic functions of our EV working: i.e. power-steering, brakes, coolant pump, cooling fan, DC-DC converter, 12 Volt system, and all high-voltage wiring. We have a few more safety features to implement before road-testing the vehicle. This is explained below.

Work Progress:

We have completed the following tasks to date, and will review each in turn:

1) Developed variable hydraulic load for testing motor control algorithms
2) Implemented power and efficiency monitoring software, along with real-time and FPGA control software.

3) Completed our TRL-6 Universal Modular Inverter Controller
4) Completed our prototype GPIC to Inverter interface board
5) Are in final stages of our EV Test-bed completion

<u>Hydraulic Load</u>

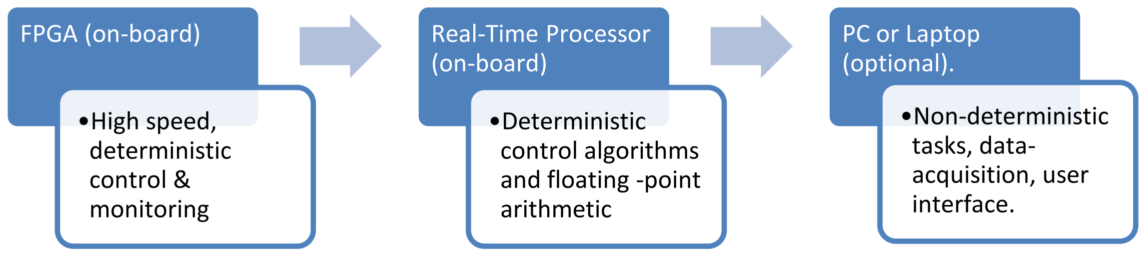
The first step we took toward developing our control algorithms was to build a miniature hydraulic load. This small system is a good model for building larger load simulators and low-cost dynamometers. This system does not measure mechanical power; rather, it provides a variable load and dissipates heat.

Figure 1 - Variable Hydraulic Load

The foreground of figure 1 shows the tank, filter, pump / motor, valve, and radiator for the load. Varying the valve allows for rapid changes in load to test control algorithm responsiveness.

Software

We have developed several pieces of control and monitoring software during this period, and have determined the software architecture for our controller. Code is executed simultaneously on three different processors to perform different functions:



FPGA Code: Our FPGA code performs high-speed, basic level tasks such as PWM or SVM modulation, fault monitoring, signal monitoring, and all I/O tasks. Loop rates of up to 250 MHz are used.

Real-Time Processor: The RT processor performs higher level tasks. In our configuration the RT chip runs the motor control algorithm. We have implemented a dual PID control loop which iterates at 250 Hz. This is fast enough to give agile response to control input or load variation for traction / propulsion motor control applications. The code can be rapidly developed on the RT platform and ported to the FPGA later for higher speeds. However, some control algorithms must be executed on the FPGA because they require higher loop speeds.

PC Processor:
Our PC interface software gives power, voltage, current, efficiency, temperature and other system feedback. The system measurement features all work and will be used next quarter during our performance evaluation. The inverter can run with or without this software. We will soon implement data storage. Our initial calibration and testing indicates an inverter efficiency around 96% at low loads.

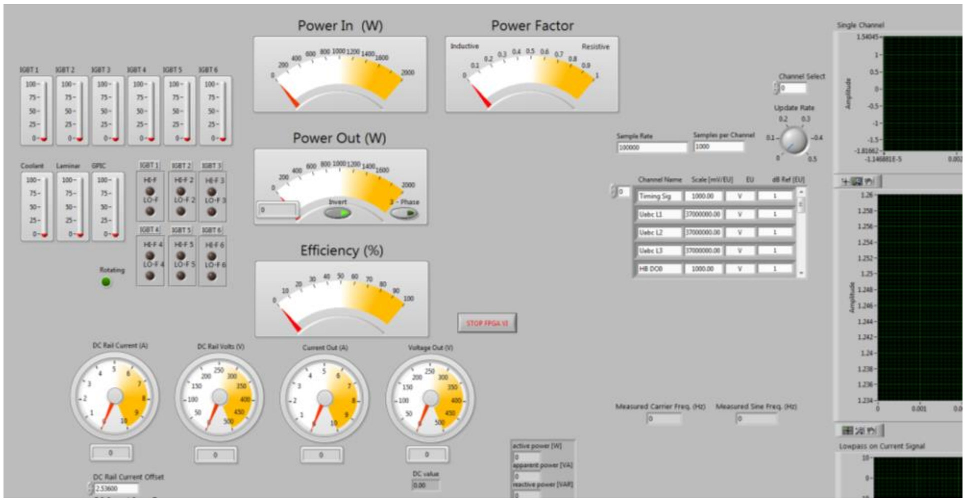


Figure 2 – Screen-shot of PC data acquisition software showing current, voltage, power, and efficiency indicators.

During our work this quarter, we decided to wait on implementing the Space Vector Modulation (SVM) algorithm. The reason is because programming the FPGA is time-intensive and we felt that other tasks were more important, such as completing the TRL-6 inverter and EV-testbed. Instead of using SVM on the FPGA, we developed a very adequate dual PID controller that runs on the real-time processor, which takes far less time to program. The SVM algorithm can be implemented later with no hardware changes. The performance of the dual PID control algorithm is very responsive and we believe it will be perfectly adequate for traction applications.

For more information and to see the hydraulic load system in action, please view these videos:

http://www.youtube.com/watch?v=PBmYoBFDluc

http://www.youtube.com/watch?v=J1ErpPHr7bY

http://www.youtube.com/watch?v=avtv6Od6pUU&feature=youtu.be

TRL-6 Universal Modular Inverter Controller

Enclosure Technology:

We have completed the TRL-6 UMIC and have installed in into the EV-testbed. Overall, it has come together very nicely and we are already learning a lot for our next revision. One key feature we have started to develop with this version is the modular housing system. This consists of water-jet cut plates from Tri-Jet Precision in Palmer, AK. This system is low cost, modular, and very rugged.

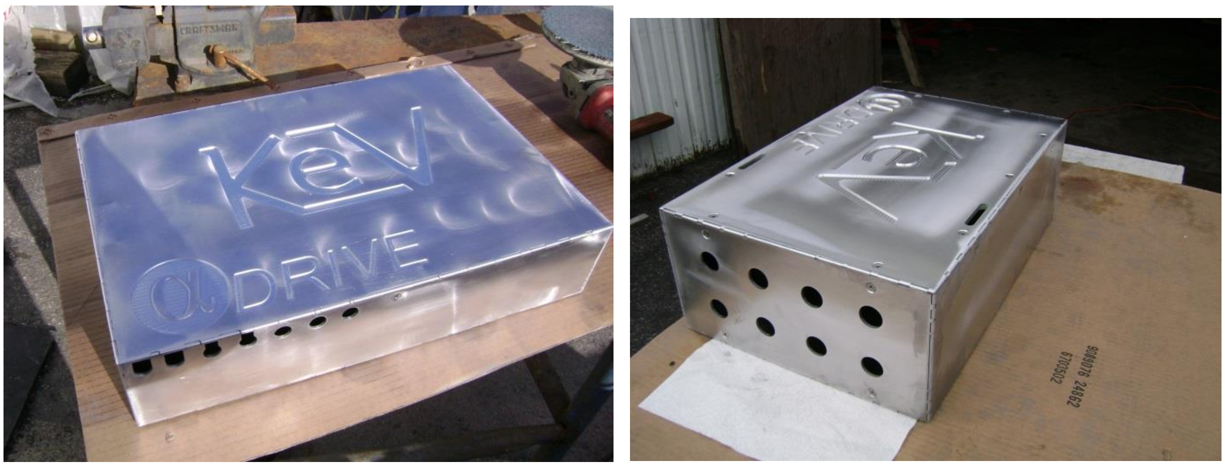


Figure 3 – Prototype Control and Data ACQ housing (left) and TRL – 6, Dual Core, UMIC housing (right)

Enclosures are assembled from 1/8” marine-grade aluminum panels. The system is rapidly developed on CAD, quick and low cost to have cut, and very easy to assemble. For our TRL-7 version we want to make this housing air and water tight.

KeV, LLC

The photo brings us to the next topic of discussion: our name. We are planning on converting to an LLC with the name KeV (Kodiak Electric Vessel). As this is our prototype system we are calling it our “alpha” drive.

IGBT Driver Woes

One difficult issue during this quarter has been non-working IGBT drivers. Our project partner, AgileSwitch, provided us with six of their second revision AS2, IGBT drivers which we were happy to beta test for them. These drivers continually faulted when used in our inverter. They sent us replacements of their previous version and these are working perfectly. The problem is that the new drivers work in their inverters but not ours. We are working with Agile to try to determine what is wrong. For now, our inverter works very well using the old style drivers.

Stacking Technology

This TRL-6 model has given us many insights into better stacking methods. This model has two power stages (a “power stage” is a layer containing up to four IGBT modules, drivers, laminar conductor, and capacitor) in a single enclosure. Future models will be a single power stage per enclosure. The reason for this design change is to minimize the effect of potential catastrophic failures, and increase ease of assembly. The fewer components which are in close proximity, the lower the cost of failures. Additionally, the single power stage per enclosure architecture is far easier to assemble, or to break-down for maintenance. We will further discuss failure mitigation below.

TRL-6 Inverter

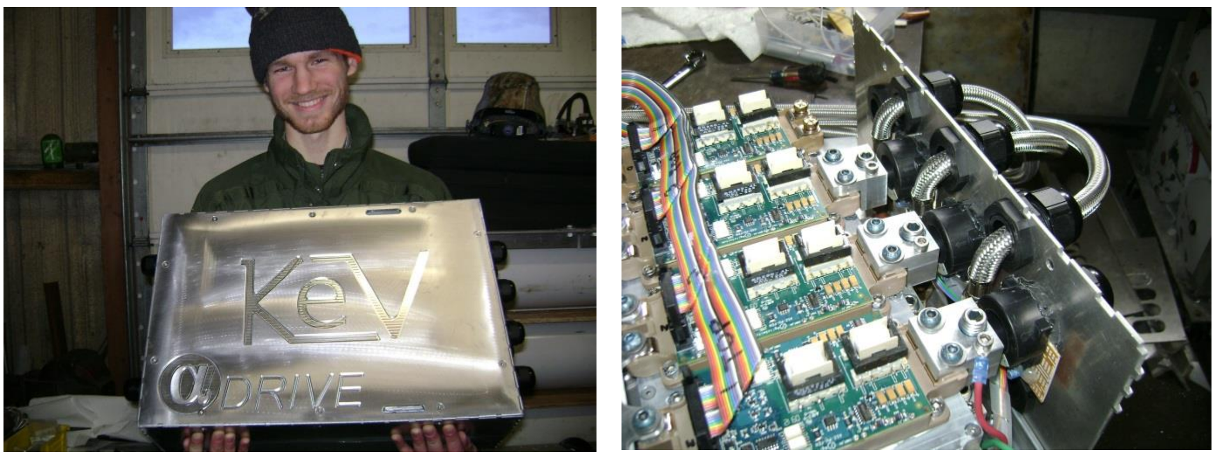


Figure 4 – (left) College student / intern holds completed "Alpha - Drive", (right) the business-end of the TRL-6 UMIC – IGBT’s, driver-cores, current sensors, and coolant lines.

Our TRL-6 inverter, the Alpha Drive, has been completed and bench-tested at low loads. It has been successfully installed in the EV and connected to main battery power at 380 VDC. With the vehicle on jack-stands we have used the inverter to spin the drive-train to around 6000 rpm and with wheel speeds of 100 mph. During these tests we were not applying more than 1/2 of the throttle range. This means we should easily be able to hit 10k rpm with our motor.

During this quarter we have successfully chosen and implemented all major inverter peripheries such as opto-isolated voltage sensors, current sensors, high-speed digital isolators, analog multiplexers, fault-line logic, DC-DC converters, and so on.

Our next step will be load testing in our EV testbed. Testing will comprise checking thermal response to load, checking enclosure thermal properties, and checking the electrical properties of the critical inverter component – the laminar bus structure. This special low-inductance bus, along with the performance of our chill-plate design will determine the maximum power rating for the inverter.

Prototype GPIC to Inverter interface board

The TRL-6 inverter is controlled by the National Instruments General Purpose Inverter Controller FPGA board. This board is interfaced to the inverter by a proto-type breadboard. Figure 5 shows the control and data-acquisition module which encloses this interface board above the inverter. The two housing modules are bolted together in final assembly. Once we replace the breadboard with a printed circuit board, the housing for the control module will be about half the thickness of our prototype housing. Figure 6, below, shows our prototype interface board.

Figure 5 - Prototype interface board is hosed in the top module, the TRL-6 inverter is in the bottom module.

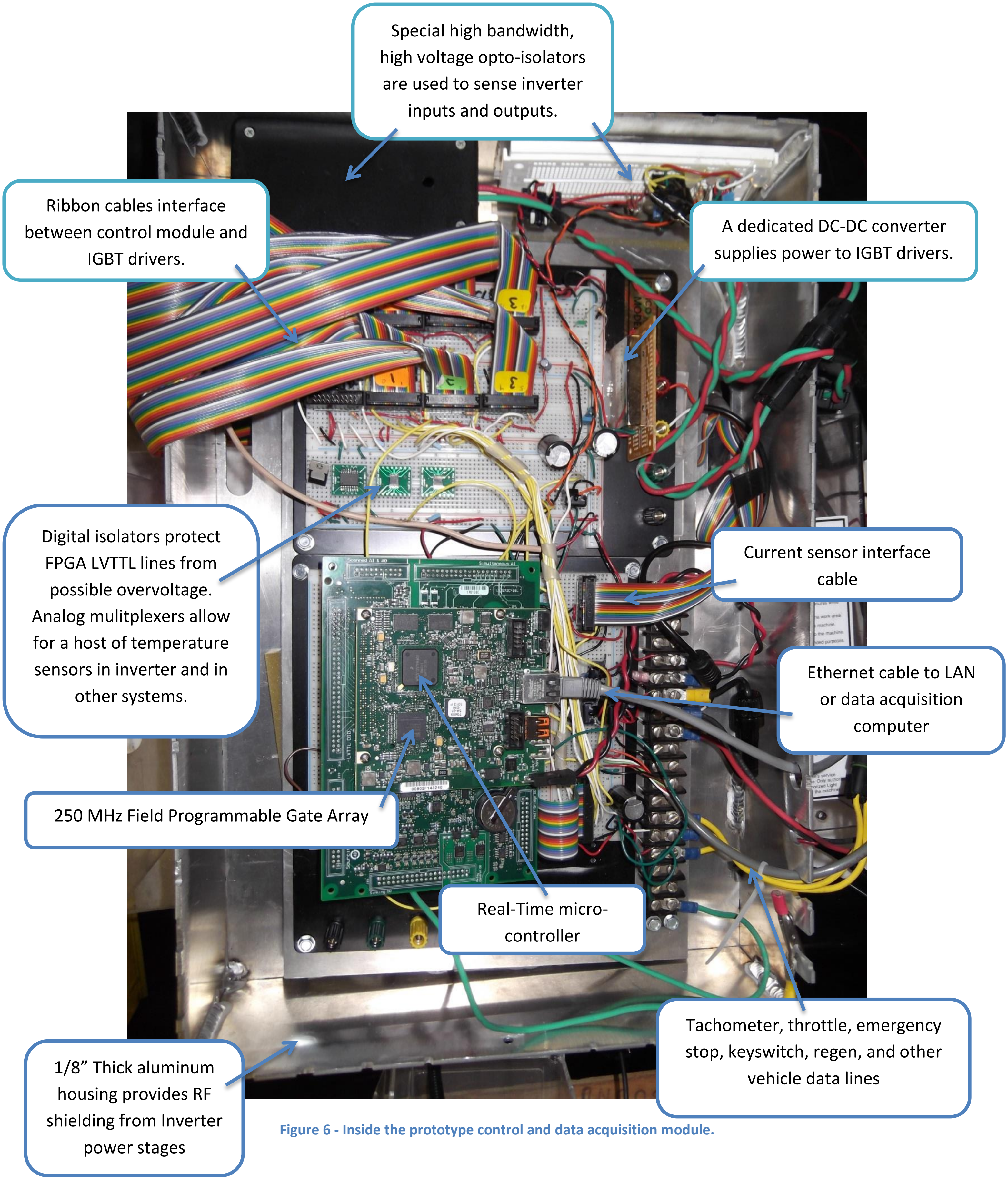


Figure 6 - Inside the prototype control and data acquisition module.

Destructive failure experience

During this reporting period we have had one component failure which has led to several design improvements and what we believe will be an important part of the IP suite associated with our products. We had a circuit breaker failure along with an IGBT shoot-through which failed an IGBT and melted a piece of one of the laminar structures. The problem originated with a software fault when downloading software to the FPGA. We have developed procedures to avoid this type of problem in the future. We also learned that breakers are ineffective for protecting IGBT's because the IGBT's are so fast. Researching the issue, we found the following strategies are used to protect high-power motor drives:

1) Fusing
2) Explosion proof enclosures

Figure 7 - Special purpose IGBT fuse

Interestingly, neither strategy is actually aimed at protecting any individual semiconductor. Rather both are aimed at mitigating the damage caused by failure. Fusing aims at protecting adjacent components within the enclosure by preventing a "burst" failure (i.e. the case of a single IGBT exploding), explosion proofing the enclosure aims at protecting components outside from failure damage. The drawbacks to fusing are added bus inductance and lower power density (because the case volume increases). The drawbacks to explosion proofing are added weight, volume, and high failure cost.

We believe there is a better path: we have in mind a laminar conductor which also acts as the fusible element. Failures on either the semiconductor or capacitor side of the inverter can be mitigated with this design. This has the advantage of being low cost, maintaining extremely low inductance, and maintaining high power density. The design is easy to build and test and we plan on implementing it in our TRL-7 revision. We are excluding any further details from this report until we are able to secure some IP protection on this novel concept.

EV Testbed Progress

Our electric vehicle testbed is nearly ready for a road-test. Students from St. Innocent's academy and Kodiak College have done lots of work machining, turning wrenches, and helping to design the systems to convert this 97 Eagle Talon into a hot-rod (hopefully!) EV. Additionally, one student taking an independent study through Kodiak College is getting engineering credit through his participation in the project.

Figure 8 – (Left) Student Nicholas fabricating front battery module. (Center) Folded box. (Right) Completed battery module!

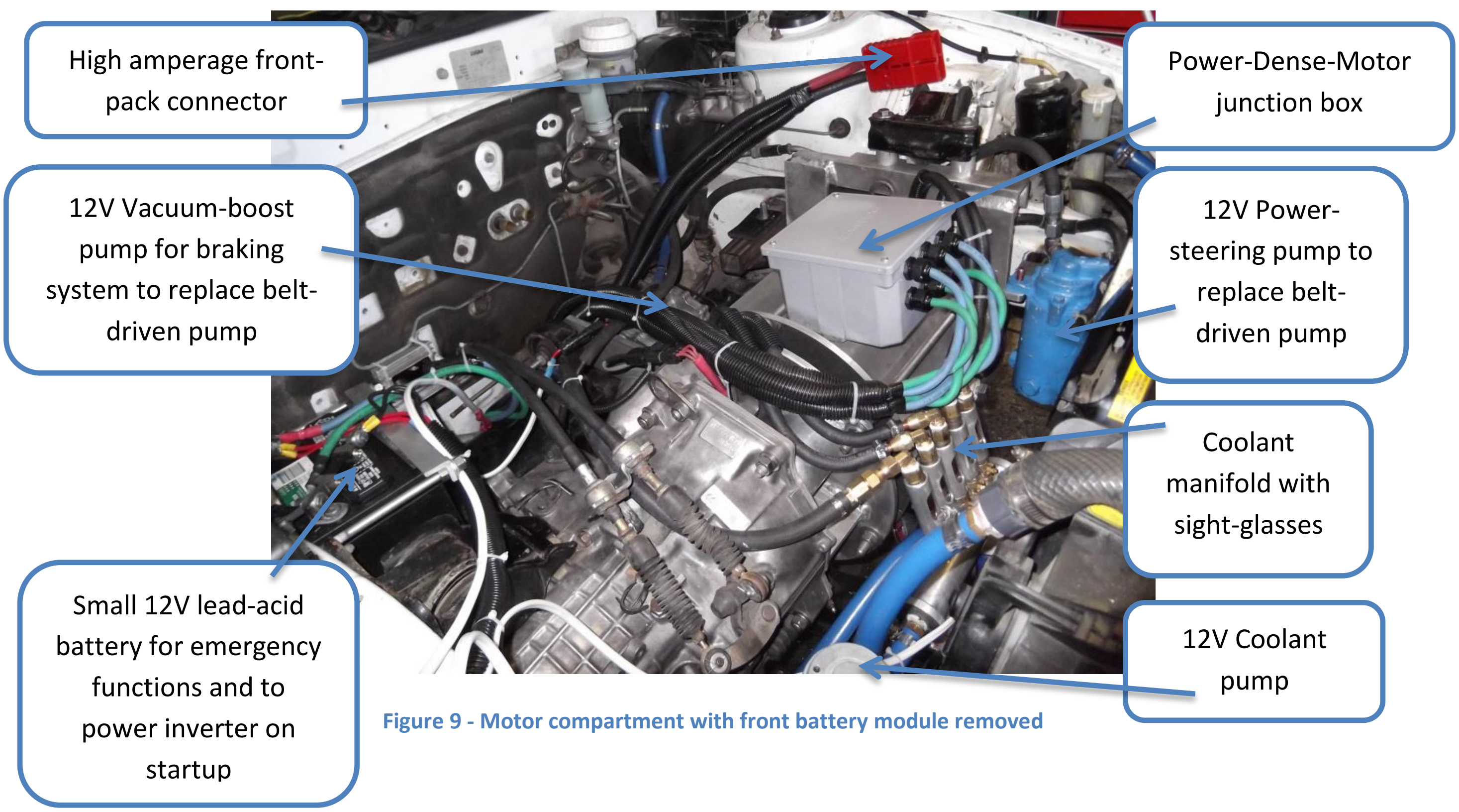


Figure 9 - Motor compartment with front battery module removed

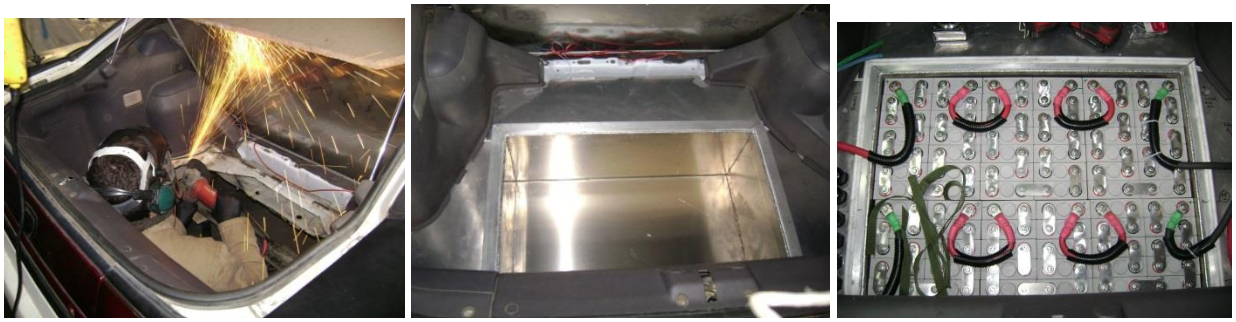


Figure 10 – (Left) Student Andrei preparing rear battery box (Center) Fabricated box (Right) Installed rear battery pack

Student test-fits inverter housing

Student Moses Cragle CNC'ing power steering pump mount

Main Contactor

Main Circuit Breaker

EV Safety Systems:

Getting the principle safety systems implemented is critical before actually driving our EV. Some of these dovetail nicely into our 2nd quarter goals of data-acquisition and performance testing. The safety systems include: continuous IGBT temperature data, motor winding temperature data, input over-current fault monitoring, three-phase current imbalance fault monitoring, IGBT driver fault monitoring, input voltage monitoring, and “kill-switch” monitoring. We are about two weeks away from having all of these systems road-ready.

Future Work:

The primary goals for the next reporting period are: 1) completing our EV safety systems, 2) performance testing our TRL-6 UMIC and PDM and submitting data reports. We will notify AEA in the next few weeks with documentation of our preliminary EV road tests.

We are anticipating that measuring the efficiency of the power-dense motor will be one of the most difficult tasks for this period. One method for accomplishing this would be installing a torque sensor between the motor and transmission of the EV. However, another simpler solution exists: it is possible for the inverter to measure the efficiency of the motor in real-time by sending a drive signal and a *load signal* simultaneously. This is a novel technique developed and tested by two Australian engineers. [1] While less straight-forward than traditional efficiency measurement methods the technique is relatively simple. We plan on implementing this method during this period because of the cost and complex mechanics of installing a torque sensor and because it will add greater functionality to our inverter products. There may be a whole market base which would want to use the inverter solely to measure efficiency!

References:

[1] C. Grantham and D.J. McKinnon, “A Rapid Method for Load Testing and Efficiency Measurement of Three-Phase Induction Motors”, Electrical Machines and Systems, 2008. ICEMS 2008, pp. 160-165, 2008.